LA-UR-19-20310

Title: A Traditional Look at SPE Phase 1 Surface Seismic Data

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Intended for: Report

Issued: 2019-01-16

A Traditional Look at SPE Phase 1 Surface Seismic Data

Far-Field Instruments, Measurements, and Analysis

Trimmed version of LA-UR-18-31678

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January 8, 2019

Abstract

We visually examined surface seismic data from the Source Physics Experiment (SPE) Phase-1 chemical explosions in preparation for waveform analysis and interpretation. Recording stations included far-field (near source) geophone lines, and both permanent network, reoccupied USArray, and temporary stations at local and regional distances. We found that near-source waveforms are dominated by broad band compressional (P), and band limited surface wave (Rg) (< 10 Hz) phases. Distinct, consistent shear (S) phases are difficult to observe visually even with a comprehensive bank of frequency bands. Secondary phases are indistinct at near-local distances, unlike for earthquake sources, especially at the high frequencies of interest for discrimination (e.g. 4-8 Hz), likely due to intense near surface scattering. S phases begin to emerge from the scattered background at and beyond 100 km. We identified regional Pn, Pg and Lg phases to 446 km for SPE-5. The data set is, unfortunately, plagued by poorly recorded instrument responses, or, possibly, time varying site amplification due to human interaction with sensors. Instrument response issues should be fixable, and this should be attempted to make this a truly, high-quality data set for use by the monitoring community.

Introduction

The SPE Phase-1 project was designed to study near-source data along with data from more typical monitoring offsets, and includes ground truth, to develop our physical understanding of source and propagation effects (Snelson et al., 2013). In the following, we describe efforts made to visually examine Phase-1 surface seismic data, understand basic propagation effects, including a search for S phases, and apply quality control. These efforts precede spectral ratio studies (Phillips et al, 2019; this volume), which have allowed us to constrain source models and understand the generation of regional phases in terms of near-source scattering of Rg and Rg coda.

Research Accomplished

Data

SPE seismic data include near-field borehole accelerometers, far-field geophones along five lines with 100 m spacing, reoccupied Transportable Array sites, and independently operated stations from Nevada, Southern Great Basin, Utah, Arizona, and CalTech networks. Far-field stations were increasingly augmented with horizontal channels as the experiments proceeded. These stations were run with sample rates of 500 Hz.

Results

We picked local and regional phases as experiments occurred. Figures 1-3 show waveforms at regional, local, and experiment level scales, respectively, for SPE-5, our largest Phase-1 explosion, bandpassed at 4-8 Hz. We focus on this band because it typically functions well to discriminate between explosions and earthquakes using P/S ratios.

Recordings at and beyond 100 km begin to show typical Pg and Lg phases, as well as Pn at the longest distances. Station WVA, Winnemucca Valley, at 446 km (Figure 1, NW corner) is the most distant station at which regional phases are observed for SPE-5.

We attempted to pick shear waves at all distances, using a broad bank of filter bands; however, standard manual picking methods gave inconsistent results (between bands, between nearby stations) at near-source and local distances. For earthquakes, we expect to observe P and S waves at all distance ranges, which is markedly different from the explosion observations, particularly at the local scales shown in Figure 2. Explosion waveforms are of high SNR at local distances, but envelopes appear featureless after the first P, relative to what we expect from earthquakes. This has to do with differences in source, or near source path effects between the two source types; it is likely that the shallow explosions generate much more Rg, which scatters into the somewhat featureless time series that we observe.

Near-source data is dominated by Rg and Rg coda, especially for lower bands. Figure 4 shows SPE-5 envelopes in perspective view for station L1020 at 2 km distance. While picking, we noted that peak amplitudes occur at Rg velocities of 2 km/s or less for bands under roughly 10 Hz, and at P velocity (4.7 km/s) for bands above 10 Hz (see Rowe and Patton, 2015). The break between the two dominant phase types can be seen in Figure 4.

We show a similar perspective plot of Nevada Array envelopes, distance 240 km, for SPE-5 in Figure 5. These envelopes are of high SNR for P and S waves for bands above 1 Hz.

When processing amplitude data, we noticed that scatter between stations and channels was quite large, and there were many significant flyers from the near-source geophone array. Such observations generally indicate instrument calibration mistakes. Standard geophones feature a stake which is pushed into the ground during deployment, and the instrument remains exposed to weather. Geophones are designed for short operational periods. Thus, the geophone array cannot be expected to be of observatory quality as rain, weathering, and human readjustment can affect the site response (we are aware that some geophones were rotated mid experiment to improve azimuths).

Discussion and Conclusions

The signal-to-noise ratio (SNR) of the regional seismograms varies greatly, and depends on propagation path quality and recording site noise. Attenuation maps based on amplitude tomography using USArray data show that crustal phases propagate well within the Basin and Range province; however poor propagation is expected around the edges where the Basin and Ranges meets the Colorado Plateaus, the Snake River basin, and the Central Valley-Sierra Nevada block (Phillips et al., 2014). Further, areas such as the Walker Lane are anisotropic, with high attenuation directions across the grain of the topography (Phillips et al., 2008). Effects of these structures can be seen in the poor recordings outside the Basin and Range in Figure 1, although high noise can also be responsible for some of these.

The featureless high frequency records we see at near-local distances is likely the result of strong Rg that is heavily scattered in near surface media. For earthquakes at seismogenic depths we expect to see distinct P and S phases at these distance ranges, indicating a very different propagation environment for explosion phases at these ranges. This will be important as we later interpret regional phases as near-source scattered Rg due to frequency dependent modulations common to all distance ranges.

To examine instrument issues, we plotted midnight noise traces over time (e.g. station L1001, Figure 6). The station shown is not special, it is just the first, numerically. Ideally, we would see the same noise measurements across time, after instrument correction, allowing for seasonal variations, and local cultural activity.

In the SPE case, the noise levels shift at times where instrument adjustment were known to be made, such as sample rate changes before and after experiments, as indicated by time and endtime fields from the project sensor table. In particular, we see subtle changes for L1001 between SPE-3 and SPE-4 (there was no SPE-4 explosion, but noise can be measured), and between SPE-4P and SPE-5. Therefore, we have considerable time intervals where noise levels do not change (SPE-1 to SPE-3, SPE-4 to SPE-4P, and SPE-5 to SPE-6).

We cannot explain these observations with weather changes, or with one trip to readjust instruments. Either multiple readjustments were performed, or we are seeing calibration issues. The fact that shifts are similar for all bands indicates that the problem could be poorly documented gain levels. We hope that this is true; if poor documentation is responsible, problems likely can be fixed. UNR investigators inform us that calibration pulses are available for these data, and we hope to examine those in the future (Ken Smith, personal communication). As data quality control absorbed undo amounts of our SPE efforts, we should take it upon ourselves to identify, and fix the response data if possible, so that others do not have to rediscover the same issues.

Acknowledgements

The authors are thankful for discussions with Ken Smith, Gabe Plank, Seung-Hoon Yoo, Gene Ichinose, and Rob Mellors. This research was supported by the US DOE under contract DE-AC52-06NA25396.

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Figures

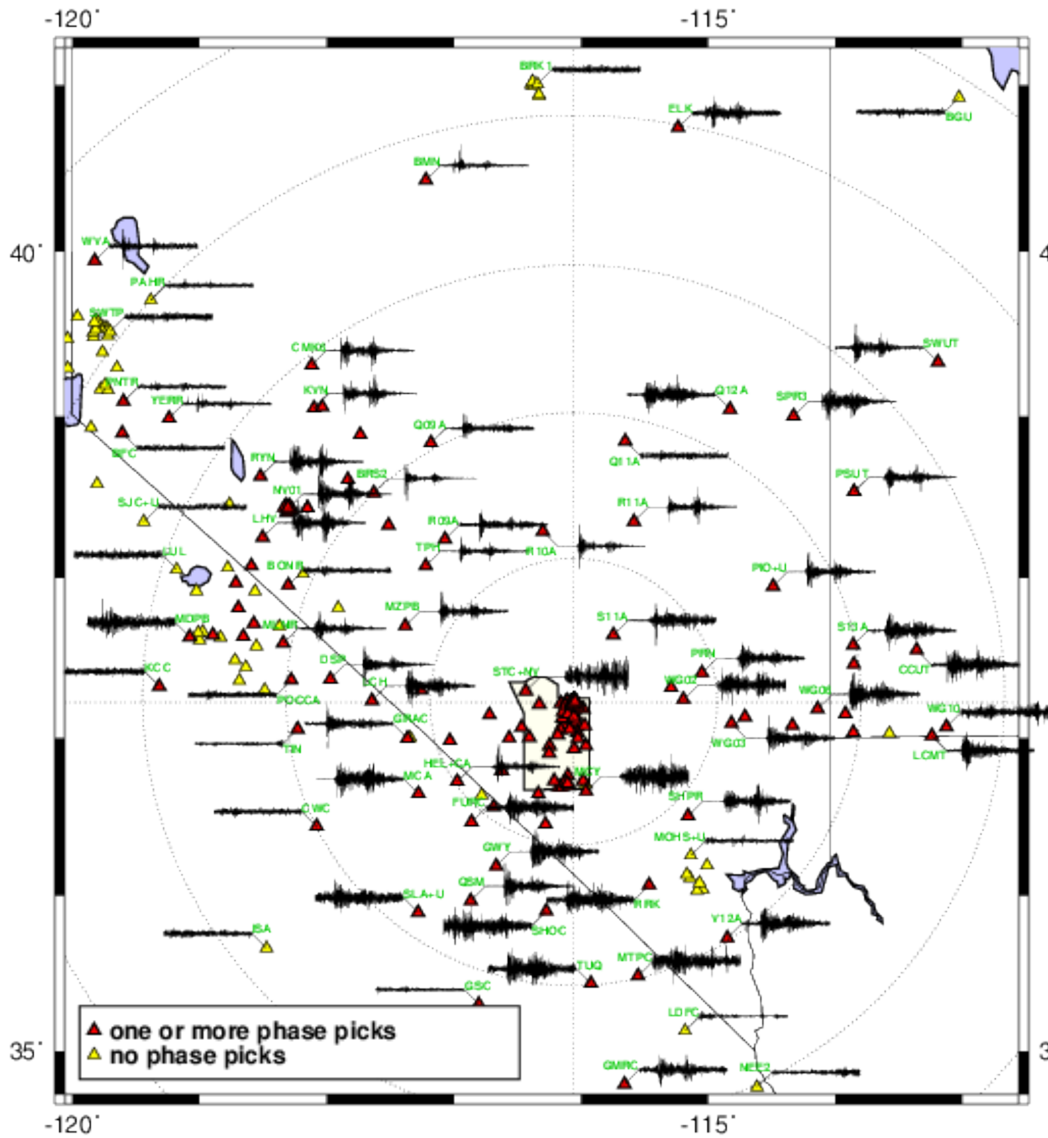

Figure 1. Regional distance stations (triangles), and selected waveforms for the SPE-5 experiment. Vertical component waveforms are shown, band 4-8 Hz, group velocity range 12-2 km/s. Distance from the SPE site are marked in 100 km increments. Stations for which we have made a manual arrival time pick are colored red, others, yellow, as indicated by the legend.

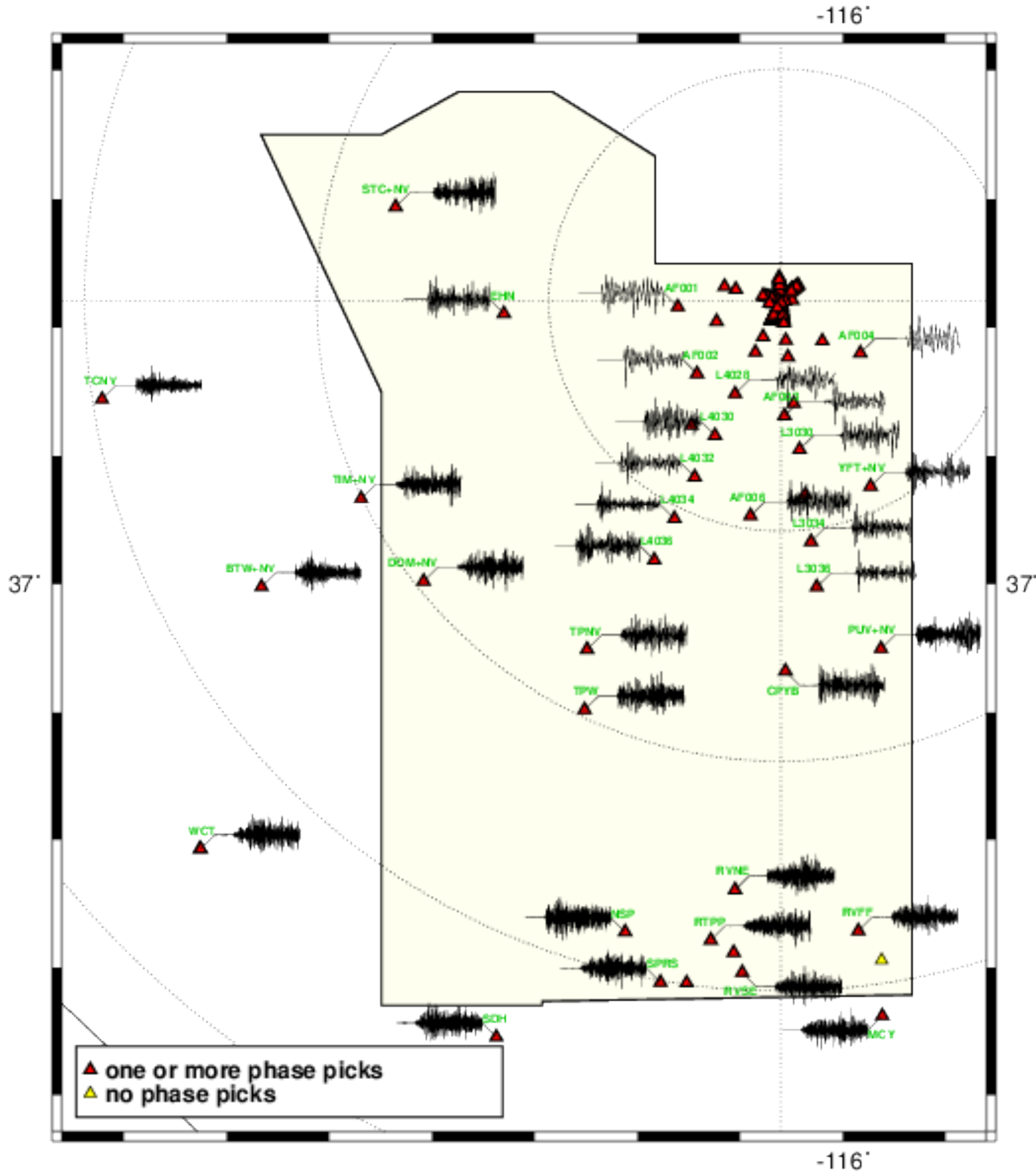

Figure 2. Local distance stations (triangles), and selected waveforms for the SPE-5 experiment. Vertical component waveforms are shown, band 4-8 Hz, group velocity range 12-2 km/s. Distance from the SPE site are marked in 20 km increments. Stations for which we have made a manual arrival time pick are colored red, others, yellow, as indicated by the legend.

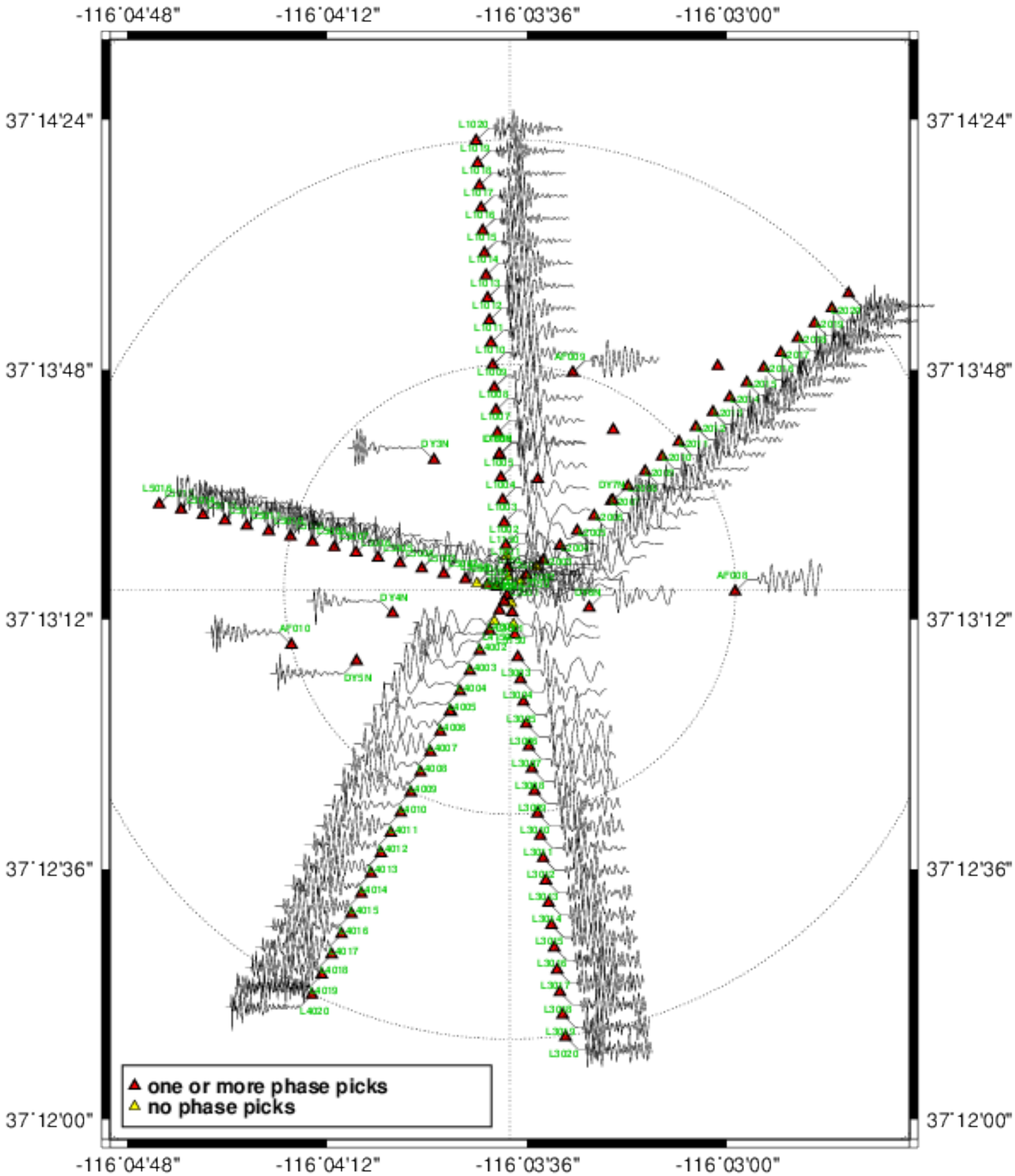

Figure 3. Far-field (near-source) geophone stations (triangles), and selected waveforms for the SPE-5 experiment. Vertical component waveforms are shown, band 4-8 Hz, group velocity range 12-0.5 km/s, with a minimum time segment 0.5 s. Distance from the SPE site are marked in 1 km increments. Stations for which we have made a manual arrival time pick are colored red, others, yellow, as indicated by the legend.

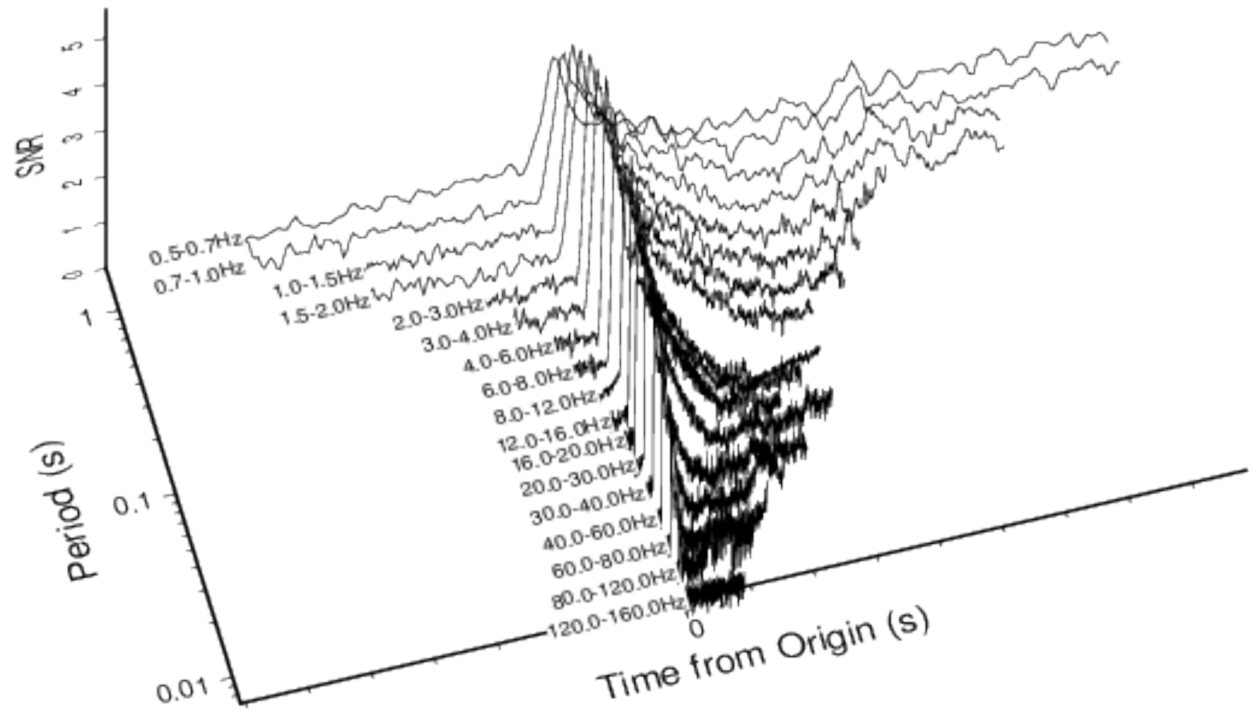

Figure 4. $\log_{10}$ SNR in perspective view for SPE-5 recorded at station L1020 channel DHH (stacked horizontal components) at 2 km. L1020 is the northernmost station, Figure 3. Time tick marks are one minute apart.

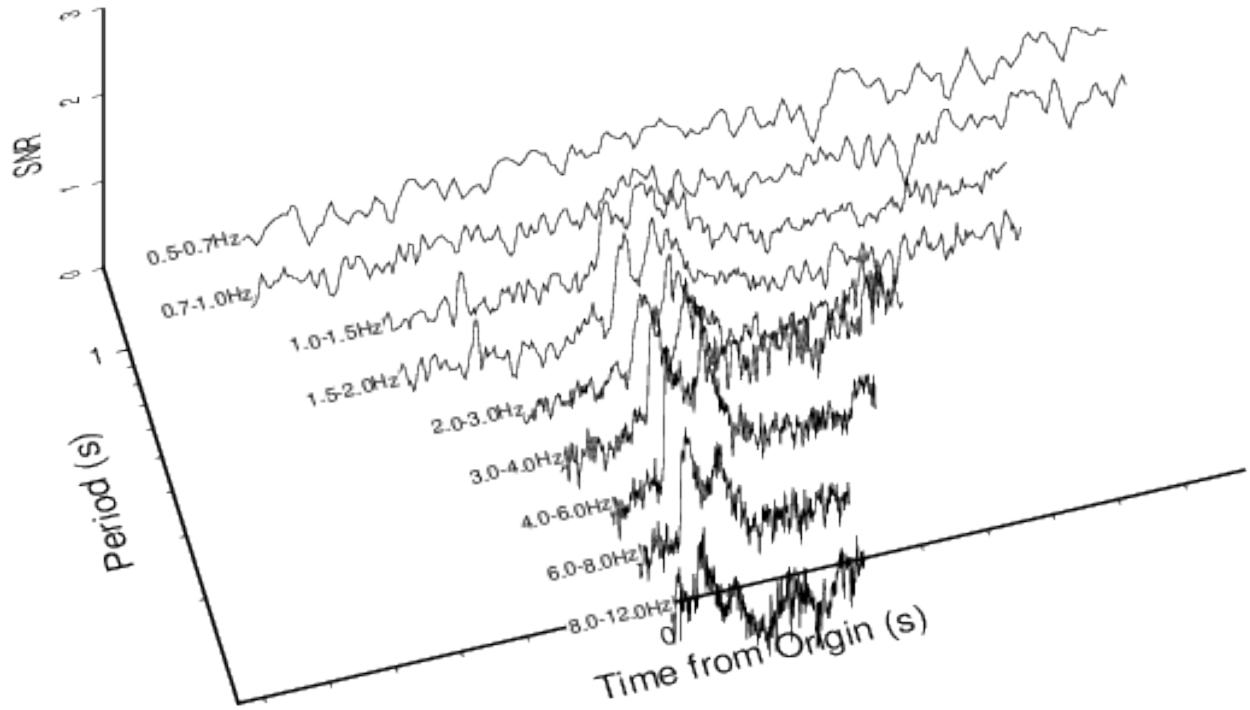

Figure 5. $\log_{10}$ SNR in perspective view for SPE-5 recorded at the NVAR array, channel DHH (stacked horizontal components) at 240 km. Time tick marks are one minute apart.

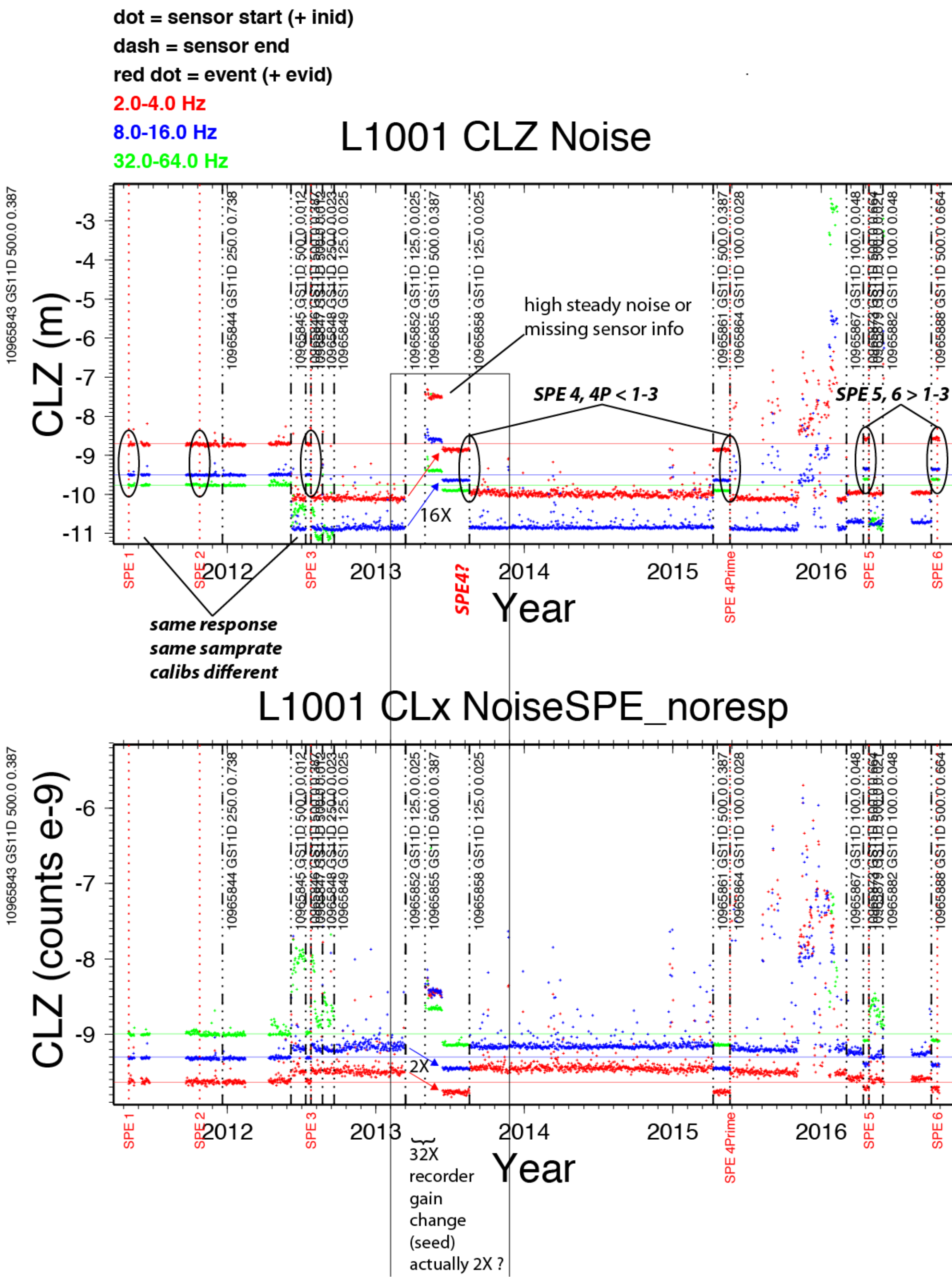

Figure 6. Midnight noise time series, with (top) and without (bottom) instrument correction, for station L1001, channel CLZ. See legend upper left for details.